**Report on 2021-2022 METplus Training Sessions and 2022 DTC METplus Users' Workshop**

John Opatz[1,4], Keith Searight[2,3,4], Tara Jensen[1,4]
[1] National Center for Atmospheric Research/Research Applications Lab (NCAR/RAL)
[2] Cooperative Institute for Research of the Atmosphere (CIRA)
[3] National Oceanic and Atmospheric Administration/Global Research Lab (NOAA/GSL)
[4] Developmental Testbed Center (DTC)

## 1. 2021-2022 METplus Training Series

The 2021-2022 METplus training series was built to instruct attendees on the basics of the METplus program, spanning the basics of the verification suite and eliciting feedback from the attendees at regular intervals to guide the structure of later classes. While meeting dates were kept to Tuesdays at 9 AM Mountain Time (MT) to accommodate attendees from the various time zones, some weeks were skipped to allow for holidays and known community meetings that conflicted with the established meeting time.

The first training series session began on Tuesday November 30th at 9 AM MT, which covered tutorial basics, an outline of upcoming session topics, how to set up METplus, and breakout sessions to cover the various environments to which users might have access. These environments ranged from Amazon Web Service (AWS) instances, the National Center for Atmospheric Research (NCAR) Cheyenne server, and the National Oceanic and Atmospheric Administration (NOAA) Hera and Jet High Performance Computer (HPC) systems. There were approximately 180 attendees, marking the largest attendance of the training series.

The following is a list of the additional seminar dates and topics, as well as the attendance of each training date:

- Session 2
    - Date: December 7th, 2021
    - Topics covered: The plot-data-plane tool, use of Python embedding for gridded data, and the pcp-combine tool
    - Attendance: 161

- Session 3
    - Date: December 14th, 2021
    - Topics covered: The gen-vx-mask tool, as well as a hands-on demonstration of the gen-vx-mask and pcp-combine tools
    - Attendance: 130

- Session 4
    - Date: December 21st, 2021

    - Topics covered: The grid-stat tool, including setting up and successfully running a GridStat METplus use case
    - Attendance: 103
    - Additional information: The first of three training series check-ins was created and distributed to attendees. In the format of a Google Forms, we captured attendee feedback related to the presentation and hands-on section lengths, ranked priority of upcoming session topics, and what they felt was the most useful aspect of the series thus far. We also collected any comments or suggestions they had on the future direction of the training series. The poll was kept open until January 19th, 2022 and collected 43 responses. Responses were overwhelmingly positive, with 90.8% of respondents ranking the overall quality of the presentations so far at 8 from a 1 to 10 ranking (10 being the highest). Priority of upcoming session topics was used to arrange the upcoming series order, with more time dedicated to those topics that ranked higher priority.

- Session 4 repeat
    - Date: January 4th, 2022
    - Topics covered: This session was a repeat of the December 21st, 2021 session. The topics of grid-stat, including setting up and successfully running a GridStat METplus use case, were re-discussed, with the same materials presented
    - Attendance: 91

- Session 5
    - Date: January 11th, 2022
    - Topics covered: Going over METplus logging and connecting MET configuration options to their METplus configuration counterparts
    - Attendance: 116

- Session 6
    - Date: January 18th, 2022
    - Topics covered: Controlling timing options in METplus with a hands-on demonstration, followed by how to properly configure METplus for filename templates
    - Attendance: 102

- Session 7
    - Date: January 25th, 2022
    - Topics covered: This was the first of two question and answer sessions, designed to provide user-specific support and better understand the verification areas where attendees were currently focused. 16 questions were gathered by Slido poll and answered in person by METplus team experts, as well as in a shared Google Docs to allow for later review by all attendees.
    - Attendance: 61

- Session 8
    - Date: February 1st, 2022
    - Topics covered: The pb2nc tool features were covered and demonstrated, which was paired with a demonstration of the ascii2nc tool. This tool focused more on the combined usage of Python embedding, a capability shared with most MET tools that was also discussed.
    - Attendance: 94

- Session 9
    - Date: February 8th, 2022
    - Topics covered: This was an extended look at the point-stat tool, diving into more use case applications that included upper air verification and a demonstration of common problems encountered during a CONUS area point data verification.
    - Attendance: 85

- Session 10
    - Date: February 15th, 2022
    - Topics covered: Two of MET's "bulk" statistical tools, stat-analysis and series-analysis were covered, with configuration options explained as well as live demonstrations of the two tools.
    - Attendance: 81

- Session 11
    - Date: February 22nd, 2022
    - Topics covered: This session deviated from the standard approach of other sessions (tool introduction, configuration options, and concluded with a demonstration). Instead, attendees were provided a live demonstration of installing MET and METplus, which extended into the library dependencies each requires.
    - Attendance: 56
    - Additional information: The second of three training series check-ins was created and distributed to attendees by Google Forms, following the first check-in style. The survey was left open until March 8th for a total of 15 days. 28 responses were collected during that time. Through 7 questions, it was discovered that less than 18% of the respondents were "often using" the available AWS instances, allowing the METplus team to scale back those instances and save resources. This also marked the first time that the learning preference of attendees for hands-on demonstrations was recorded, with over 60% responding that they "listen and perform the steps later on [their] own time". The feedback for the Q&A session was completely positive (60.7%, with the remaining 39.3% responding that they did not attend the session), indicating that a follow-up Q&A session near the end of the series would be warranted. Responses were still positive to the second set of sessions (session 4 to 9), with a majority of respondents indicating that demonstrations and tool discussions were timed "just right".

- Session 12
    - Date: March 1st, 2022
    - Topics covered: The focus of this session was on tropical cyclones. Specifically, tc-stat and tc-pairs were discussed and demonstrated, followed by tc-rmw and tc-gen.
    - Attendance: 79

- Session 13
    - Date: March 8th, 2022
    - Topics covered: With the latest stable release (version 4.1.0) available to the public, the METplus team presented highlights from the release, going over release notes and general tol improvements.
    - Attendance: 79

- Session 14
    - Date: March 15th, 2022
    - Topics covered: The newest ensemble verification tool, gen-ens-prod, was covered and demonstrated. This was followed by the original ensemble verification tool, ensemble-stat, which had its own configuration options discussed and presented in a METplus use case.
    - Attendance: 76

- Session 15
    - Date: March 29th, 2022
    - Topics covered: While the second check-in survey revealed a minority of respondents utilized the available AWS instances for running METplus, this may have originated from a lack of support and understanding of the capabilities. In addition, the AWS instances provides a quick and reliable METplus access point for newer members and verification centers. To better assist those users, this session was dedicated to running METplus on an AWS instance using live data, a focus area that was largely supported by respondents in the first check-in survey.
    - Attendance: 73

- Session 16
    - Date: April 5th, 2022
    - Topics covered: Focus shifted to the visual verification area of METplus, discussing the METviewer and METexpress applications.
    - Attendance: 74

- Session 17
    - Date: April 12th, 2022

    - Topics covered: Two of the newer METplus applications were covered, METcalcpy and METplotpy. This was another of the top-requested topics from the first check-in survey, so an entire training session was dedicated to them.
    - Attendance: 72

- Session 18
    - Date: April 19th, 2022
    - Topics covered: Like the tropical cyclone focused session 12, this session was specific to subseasonal to seasonal (s2s) applications of METplus. Several existing use cases in the METplus repository were demonstrated, including a weather regime and Outgoing Longwave Radiation (OLR)-based MJO index (OMI).
    - Attendance: 57

- Session 19
    - Date: April 26th, 2022
    - Topics covered: For the final training series session, the spatial verification tools, MODE and MODE-TD were covered.
    - Attendance: 61

- Session 20
    - Date: May 10th, 2022
    - Topics covered: This was the last session, and the second question and answer session to directly engage with attendees and their specific METplus applications. The questions were once again gathered by a Slido poll, culminating in 10 questions that were answered during the session.
    - Attendance: 53
    - Additional information: The final training series check-in was distributed to attendees on June 7th, with a delay between the last session and distribution of the survey due to delayed team feedback and focus shifting to the upcoming DTC METplus workshop. This delay contributed to a smaller response pool, with only 9 recorded responses. Feedback remained overwhelmingly positive, with over 75% of respondents responding with a 4 or 5 to rate their overall satisfaction with the training series (on a scale of 1 to 5, with 5 being “extremely satisfied”).

**2. 2022 DTC METplus Users’ Workshop**

The Developmental Testbed Center’s METplus Workshop was hosted over the course of 3 days, beginning on June 27th and concluding on June 29th. The intent of the workshop was to bring the METplus community together to discuss the use of the system and learn how others use it. The initial session provided a brief overview of the METplus verification suite, including a description of the latest verision’s updates and capabilities. The METplus development team also devoted time to presenting on how the METplus community can contribute code and use cases to continue development in their areas of focus. Participants were also invited to present

the use of the tools for their model evaluation needs. Registration was opened and recorded over 290 registrants during open enrollment, with a separate call for presentations. That call for abstracts gathered 30 participants willing to talk about their METplus usage, ranging from 15 to 20 minute talks. While creating the agenda for each day, special attention was given to the time zone of each speaker to prevent extremely late or early speaking times for the speakers. To further accommodate this need, each day of the workshop began at 8:30 AM MT.

Day 1 activities began with an overview of the METplus verification suite, paired with the current capabilities of the system, divided into three broad areas: the statistical center (MET), the simplified wrapper applications (METplus wrappers), and the visualization component (METplus Analysis). Beginning the workshop in this manner allowed all attendees to start with the same knowledge base, regardless of their given backgrounds and experience level with METplus. After a brief break the workshop quickly moved into presentations, covering how the Environmental Modeling Center (EMC), Met Office, Naval Research Laboratory (NRL), and India's National Center for Medium Range Weather Forecasting (NCMRWF) are all utilizing METplus verification products for their needs. These talks were allotted 20 minutes, which included time for questions from attendees. The workshop broke for lunch for 55 minutes, and when it resumed the focus returned to internal presentations from the METplus team. The theme of these talks was external collaboration, intended to help attendees better understand how they can become involved in the continued development of METplus. Topics included how to create GitHub Discussions, creating and adding use cases to the GitHub repository, protocols for contributing C++ code, how to add METplus Analysis scripts, creating pull requests, and examples of current contributions from the METplus community. The day concluded with two concurrent sessions of METplus user presentations with one session focused on satellite data and aerosol-focused applications, while the other session was primarily Subseasonal-to-Seasonal (S2S) scale usage. Each session hosted 5 presentations, with the day concluding at 3:30 pm MT.

Day 2 began with a survey question to engage attendees, asking "What was the hardest part of starting with METplus or what is stopping you from starting with METplus" and providing a list of pre-determined options with up to three selections possible for each respondent. The 37 responses collected showed the following four reasons were in highest agreement:

- Installation (54% of respondents)
- Difficulty with setting up config files correctly (43% of respondents)
- Intimidated by complexity (27% of respondents)
- Confusing/unclear/missing documentation (27% of respondents)

The top response, difficulty with installation, was used to generate further discussion later in the day. Day 2 presentations then began in two concurrent sessions, with the themes being object based, feature relative verification, and the technical aspect of using METplus in operational settings. After a short break, the workshop resumed to discuss the history and outcomes of previous metrics workshops, going through each of the metric sheets as a whole group and discussing how those metrics came to be and what should be done to meet the

community-driven requirements. Before the final session of the day, attendees were given the opportunity to provide feedback from the previous survey question's top answer. By a short answer Slido survey question, responders could provide their potential solutions to the installation barrier that was deemed the hardest part of starting METplus. The survey question was left open for the entire final session and reviewed post-workshop for opportunities for improvement. The final session was presented by the METplus team and covered how to further analyze METplus output and the accompanying tools, such as METviewer and METexpress. In addition to the five presentations, there was also a concurrent virtual METplus helpdesk available, where anyone that was having any trouble with the METplus system could log into the separate meeting and receive one-on-one virtual assistance. This offering was made to mimic other workshops that provided similar troubleshooting sessions, as well as to gauge what areas are causing the most issues that users need help on.

The final day was set to be a shorter day, starting with five presentations covering METplus usage in ensemble and tropical cyclone applications. To provide another helpdesk opportunity to attendees, a simultaneous virtual assistance meeting was also held. After returning from a break, the workshop entered its final phase where feedback on the future needs of the METplus community was gathered. Through the use of separate breakout rooms, attendees were encouraged to select one of the five following categories of discussion topics:

- Cutting Edge/Novel Verification Topics
- Unstructured Grids
- Operational Needs Vs Research
- Process-Oriented/Phenomenon-based Diagnostics
- Miscellaneous Great Ideas

Over the course of 30 minutes, discussion facilitators would guide conversation amongst attendees and ideas were recorded by a breakout room notetaker. After the 30 minutes were up, All of the attendees were encouraged (but not required) to find a new breakout room discussion topic that they wanted to discuss and enter for a second, 30 minute round of discussions. After these two sessions were concluded, a spokesperson for each breakout room would present the ideas from both sessions, with feedback provided from the group at large. Below is the recommendations from the breakout sessions:

- Cutting Edge/Novel Verification Topics
    - Fair scores
        - Currently have fair CRPS in the pipeline
        - Also consider fair BSS, RPS
    - Vertical dimension, time dimension (neighborhood analysis, basic interpolation in the vertical for pressure and height already exists)
    - CRPS from Series-Analysis
    - Aircraft observations vx
        - This supports a Series-Analysis, point observation option
    - Continue to expand ensemble vx methods

    - Unstructured grids [this is cutting edge and deserved a mention here as well as its own group]
    - Process-oriented vx
- Unstructured Grids
    - Variety of different *types* of unstructured grids which adds great complexity
    - Some ugrids remain fixed from run to run while others can change (i.e. moving nest) within a single run
    - Currently interpolating ugrids to a common lat/lon grid for evaluation. Seeking a better vx solution for this.
    - Interpolation/regridding has major impacts on vx results, want to minimize the impacts of interpolation
    - Need fcst/obs matched pairs for station locations as well as comparing two datasets on unstructured grids to each other, assuming they are identical
    - Should we leverage JEDI functionality for computing fcst/obs matched pairs or seek solutions directly in MET?
    - Is a general purpose solution for all ugrids feasible or do we need separate solutions for each model source. How to use the connectivity information of ugrids?
    - Lack of direct WRF/MPAS support in METplus is preventing some NCAR groups from using it.
    - How to migrate unstructured grid to regular grid for evaluation? Regridding hi-res data is very time consuming and computationally expensive.
    - **static** ugrids can define lookup tables and weights and reuse them from run to run
- Operational Needs Vs Research
    - Need to consider data management for retrospectives and developer experiments…observations, climatologies, baseline verification, etc.
    - Accessibility on various HPC; how do we support everything on different HPCs with different versions, different packages, conda environments, etc.? Try to have a better balance libraries/packages between research and operations
    - Biggest hurdle is plots/graphs using METplotpy vs. METviewer, researchers/forecasters want simple understand, straightforward
    - Support for verification for ocean models, aviation impact variables, S2S
    - Ability to do deep-dive/diagnostics into case studies (outside of the generic verification statistics like bias and RMSE) to see what went wrong or right in a model (more for a research perspective)
    - Need to have METplus to be able to follow model development be able to process/read in new model variables and output
    - Time constraints to be able to contribute to METplus development as a community member. User contribution guide exist/are being worked on, but how could the development and contributions to METplus be made easier?
    - Build community buy-in both on the research side and operational side, some are reluctant to trust it which makes them less likely to switch to using it.

    - How can community data storage be done? Data needed for METplus use cases are only going to grow! Data files researchers need shouldn't fall on the METplus team entirely though.
- Process-Oriented/Phenomenon-based Diagnostics
    - Multivariate approach focused on event
        - Currently available: Multivariate MODE (MvMODE), Feature Relative Use Cases
        - Upcoming: MvMTD
    - Improving computational efficiency especially for high resolution
    - More support for non-atmospheric models:
        - LSM: Moisture energy budget
            - Moisture feedback mechanism - PDF of rainfall and precipitable water vapor
            - Current availability: Grid-Diag tool to identify a joint PDF
            - Soil moisture - explore LVT at NASA Goddard
        - Coastal ocean processes
            - Tidal currents - periodic
            - Quasi-Stationary currents like Gulfstream
            - Ask Ilya Rivin to act as a SME on these topics
    - Tools available to process other commonly available datasets - eg DOE ARM, land and soil datasets
        - Wrappers that call out specific observation types
        - How to better use aircraft-based observations
    - Process studies: Probability Matched Mean (ask Jonathan Case to contribute his Python code)
    - Tropical cyclone diurnal cycle - AZ averaging;
        - In processes - AZ averaging
        - TC getting METplus to accept different input formats; BUFR, CSML; Error-spread plots, Track-probability forecasts, Genesis probability forecasts
        - Use cases to get field campaign data into METplus
            - Support the community to contribute their ingest scripts
            - Form a affinity group
        - METplus to compute the indices
            - Need SME to partner with to identify how to compute these - Matt R.
        - Multivariate methods
            - Available: MvMODE, Grid-Diag tool
            - Upcoming: MvMTD
        - More tropical convection diagnostics
            - MDTF diagnostic
        - More support for non-atmospheric models:
            - Mixed layer depth (phenomena), sonic depth, sound profiles, temperature profiles, GODAE

        - Metrics that are geared toward extreme events that have a relatively small sample size?
- Miscellaneous Great Ideas
    - Container technology for METviewer applications on HPC; can use singularity container for MET now
    - Transitioning scripts from R to python
    - Transferring to GNU 11
    - Expand support for GFortran for people who don't have access to commercial compilers
        - Review GNU11 compilers so scripts are compatible (e.g., FC flags)
    - Point-to-grid tool: Cressman analysis or other more sophisticated tools for interpolation
    - Verify calibrated CDFs
    - Verify on model grid surfaces rather than on pressure levels
    - MET install scripts - exist (Will H)
        - Parallelization of MET scripts to save computation
    - Installation guide tutorial needs to be enhanced (e.g., COMET module, other resources)
    - Additional use cases for rocoto or Cylk (work flow managers)
    - Use case does exist for this
    - Make info about these more available and easy to find (sometimes the
    - Point-to-point verification tool
    - Ensemble statistics on a grid (e.g., CRPS)
    - HPC - need better tools to run on different METplus
        - Containers - singularity available now
        - Base container with auxiliary environment to install METplus etc. using e.g., NSF computers
        - Could use in tutorials to demonstrate use cases (MET office has some ability)
    - Parallelization of METplus
    - Multiple jobs at one time rather than in separate jobs

Many of these ideas are already incorporated into METplus planning. The rest will be discussed with the METplus Governance Committee to help prioritize what should be in the 2-5 year plans. The workshop ended at 12:30 MT on Wednesday, June 29th.